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חוק הפטנטים, התשכ"ז-1967
PATENTS LAW, 5727-1967

מספר: 155034 Number	
תאריך: 23-03-2003 Date	
הוקדם/נדחה Ante/Post-dated	

בקשה לפטנט
Application for Patent

אני, (שם המבקש, מענו – ולגבי גוף מאוגד – מקום התאגדותו)
I (Name and address of applicant, and, in case of a body corporate, place of incorporation)

M.A.M.D. Digital Data Processing System Ltd.
32 Weizmann Street
62 091 Tel Aviv

מ.ע.מ.ד. מערכות עיבוד מידע דיגיטלי בע"מ
רחוב ויצמן 32
תל אביב 62 091

Inventor/s: Meir SHRAGAI; Joseph LIBERMAN

הממציא/ים: מאיר שרגאי; יוסף ליברמן

בעל אמצאה מכח הדין ששמה הוא:
Owner, by virtue of **Operation of Law** of an invention, the title of which is:

(בעברית) **(Hebrew)**
צילום דיגיטלי אווירי אוטומטי ומערכות עבוד נתונים ספרתיים

(באנגלית) **(English)**
Automatic Aerial Digital Photography & Digital Data Processing Systems

hereby apply for a patent to be granted to me in respect thereof.
מבקש בזאת כי ינתן לי עליה פטנט.

*בקשת חלוקה- Application for Division	*בקשת פטנט מוסף- Application for Patent of Addition	*דרישת דין קדימה Priority Claim		
מבקשת פטנט from Application No.______ מס' dated______ מיום	*לבקשה/לפטנט for Patent/Appl. No.______ מס' dated______ מיום	מספר/סימן Number/Mark	תאריך Date	מדינת האיגוד Convention Country
*יפוי כח: ~~כללי/ מיוחד רצוף בזה/~~ עוד יוגש P.O.A.: ~~general / specific — attached/~~ to be filed later Has been filed in case ______ הוגש בענין				
Address for Service in Israel המען למסירת הודעות ומסמכים בישראל G.E. Ehrlich (1995) Ltd. ג'י. אי. ארליך (1995) בע"מ 28 Bezalel Street רחוב בצלאל 28 52 521 Ramat Gan רמת גן 52 521				

חתימת המבקש
Signature of Applicant

For the Applicant
Attorney Docket No.: 25951

היום 20 בחודש מרץ שנת 2003
This 20th of March 2003

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טופס זה, כשהוא מוטבע בחותם לשכת הפטנטים ומושלם במספר ובתאריך ההגשה, הינו אישור להגשת הבקשה שפרטיה רשומים לעיל.
This form, impressed with the Seal of the Patent Office and indicating the number and date of filing, certifies the filing of the application, the particulars of which are set out above.

צילום דיגיטלי אווירי אוטומטי ומערכות עבוד נתונים ספרתיים

Automatic Aerial Digital Photography & Digital Data Processing Systems

Problem Solved by the Invention and its environment:

1. Automatic Digital Airborne Photography System.

   - Automatic Digital Airborne Photography System Equipment Configuration is based on commercial existing sub-systems integrated in specific manner in order to perform precise aerial digital photography being installed on a light aircraft and enable a single pilot to carry out the air survey task.
   - The System dramatically reduces the full process production cycle time of products based on Aerial Photographs.
   - The low weight of the airborne photography system can be installed on light general aviation aircrafts, as Cessna 172, to perform fast, flexible, low cost photography projects.

2. Automatic image data processing system

   - Automatic state of the art image data processing system enables delivery of sophisticated applications, on short notice and low cost.
   - Innovative Automatic Change Detection module enables a variety of applications and final products.

   - Automatic image data processing system enables

     - Image data Import, Store and Retrieve.
     - Tie point measurements - locate corresponding points in overlapping sets of images.
     - Triangulation solution - computation of the camera locations and orientations for all the images.
     - Control points input - interactive input of geodesic control points as measured on the ground.
     - Digital Terrain Model (DTM) - computation of the DTM based on the stereoscopic information in overlapping images.
     - Mosaic generation - combine the images into a rectified (Orthophoto) mosaic.
     - Change detection - detect and measure changes between Orthophoto mosaics of the same target, taken in different times and different light conditions.
     - Change classification - classify the detected change as belonging to a natural scene or to a man-made target.

Closest Known Related Technology:

1. Existing Airborne Photography System

   The existing Airborne Photography System. In use are based either on film aerial cameras or expensive hevy weight equipment using according to regulations two engine airplanes with on board crew of at list 3 members. The Costs of service are at least four times our costs.

2. Existing image data processing systems

   The Existing professional systems evolved from systems originally developed on Unix, transformed to DOS and lately transformed to WINDOWS. Part of the historic malfunctions remained, mainly the need of highly qualified operator.

Novelty

1. The novelty of our Airborne Photography system is the automatic features high availability and low cost operation.

2. The novelty of our Automatic image data processing system is the automatic features, low cost operation and the innovative automatic change detection module.

Advantages of the Invention:

- Dramatically reduce full process production cycle time.
- Using of proprietary airborne system enables using of light general aviation aircraft to perform fast, flexible, low cost photography projects.
- Very effective automatic image processing enables to deliver sophisticated fast relatively low cost (new) applications.
- Innovative - Change Detection Process opens new scale of applications.
- Enabling fast low cost measurement- projects of dynamically changed terrain and objects.

Full Description of the Invention:

Patent registration

on

Automatic Aerial Digital Photography & Digital Data Processing Systems

Subject No 1

Automatic Digital Aerial Photography System Equipment Configuration

The Automatic Digital Airborne Photography System Equipment Configuration is based on commercial existing sub-systems integrated in specific manner in order to perform precise aerial digital photography being installed on a light aircraft and enable a single pilot to carry out the air survey task.

The system contains the following sub systems: -

a. Navigation Guidance & Control System is based on the following elements:
    i. Mission Computer passed on commercial Laptop,
    ii. GPS unit,
    iii. Pilot Display unit.

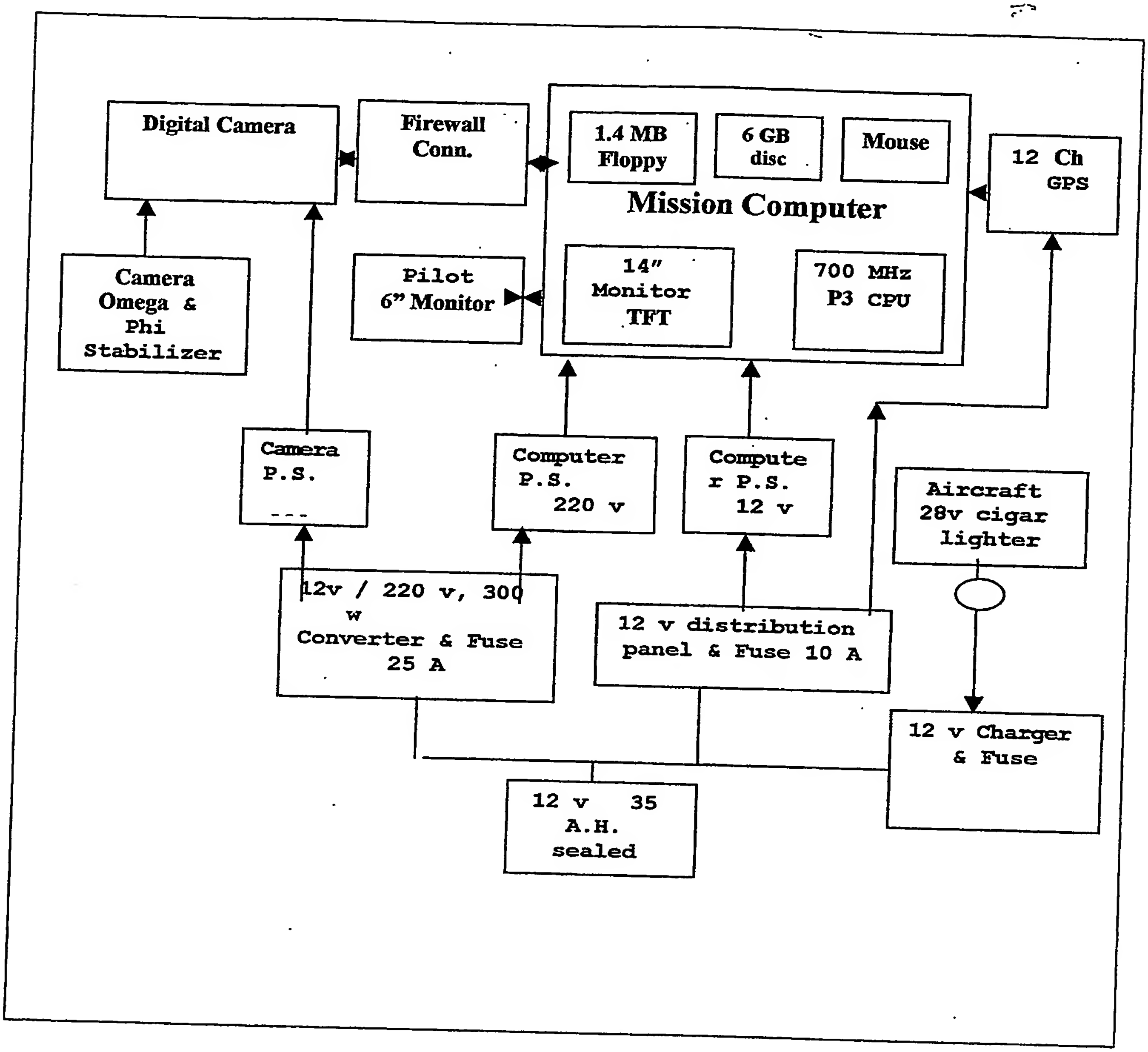
    The System enables to do the mission planning, to guide the aircraft over the appropriate ground track, and at the correct altitude. On planned locations according to the mission plan, it activates automatically the photography system.

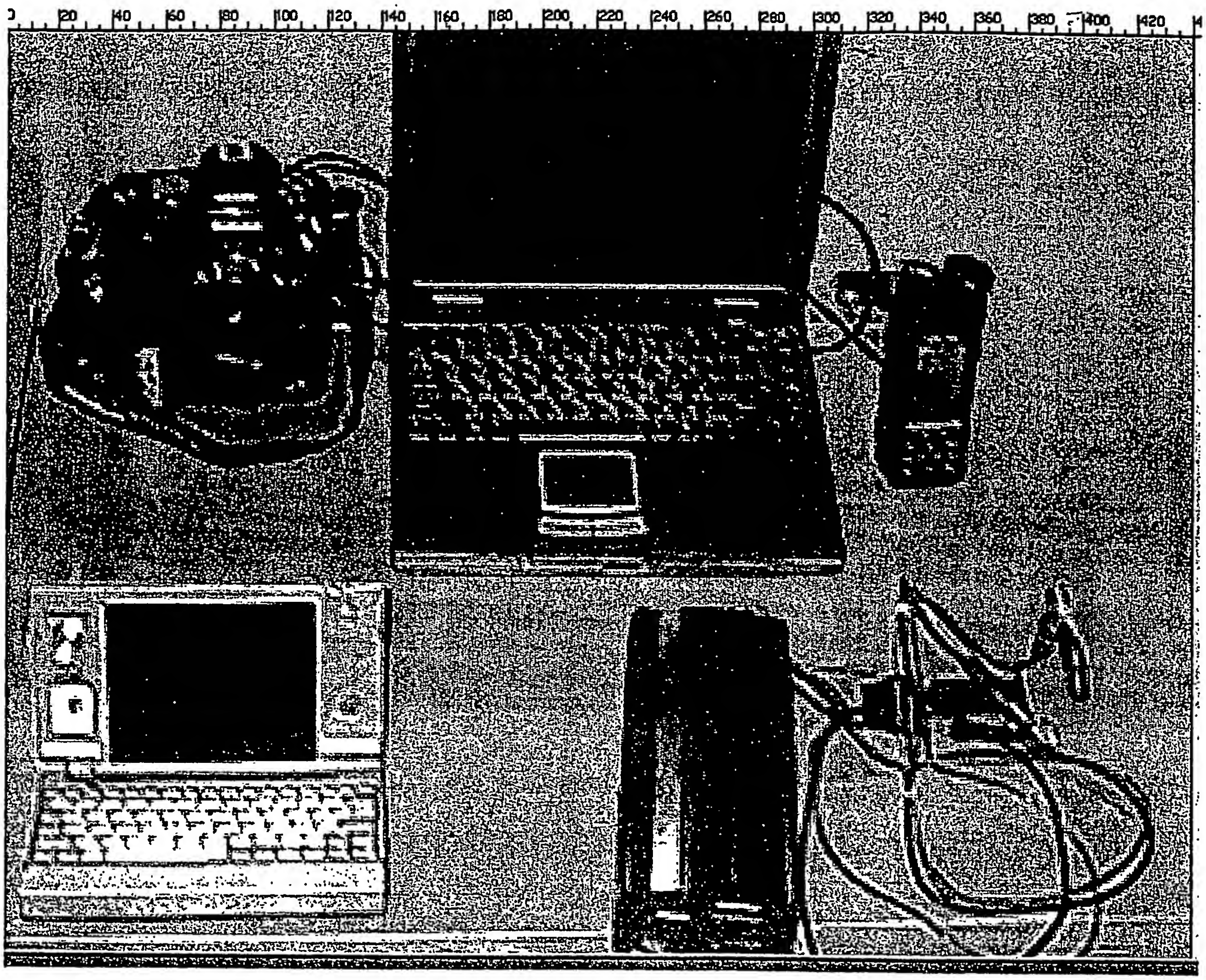
b. The Photography System is based on the following elements: -
    i. Digital Electro-optical camera.
    ii. Payload Stabilizer Mount.
    iii. Storage capability on the Mission Computer of the image files from the camera together with position data from the Navigation Guidance & Control System.

The system is designed to be installed on Cessna 172 light Airplane according to the System Installation Diagram.

On the Prototype system the camera is installed on a manually stabilized rigid stand. Further a Payload Stabilizer will be integrated in order to improve performances.

Table Number 1: Airborne System Configuration)





Subject No 2

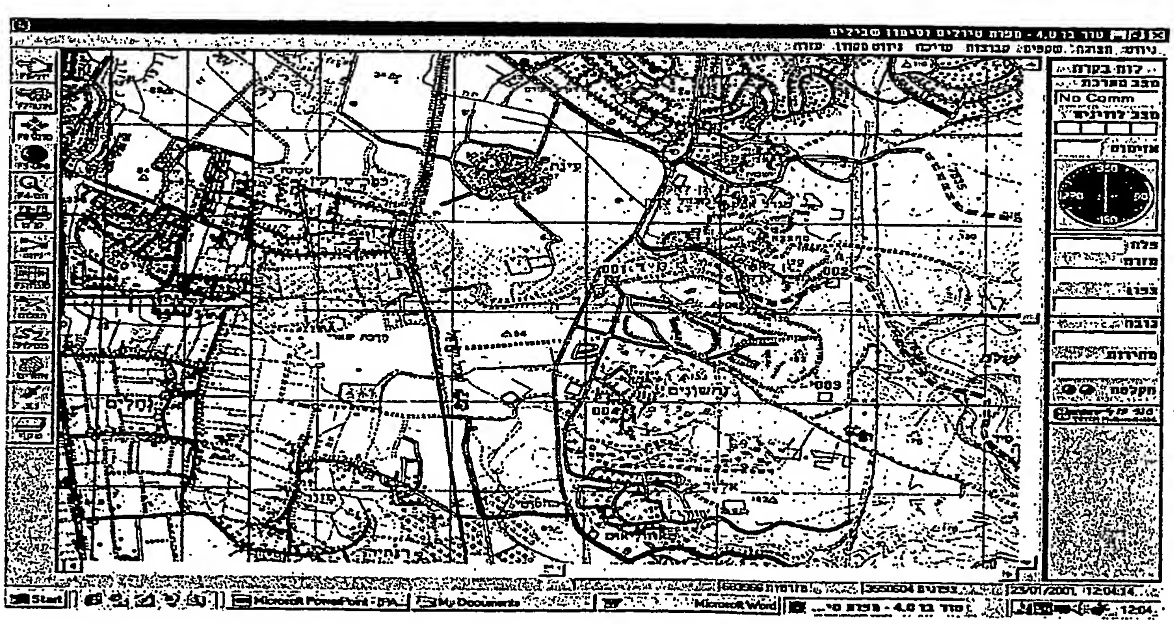
Automatic Digital Airborne Photography Software System Configuration

Software System of the digital aerial photography system is based on existing software building blocks and complimentary software modules. The software elements were adapted and integrated as a system to fulfill the desired operational functions and tasks. This software runs on PC computers on ground and on board. The programs are written in c++ and visual basic.

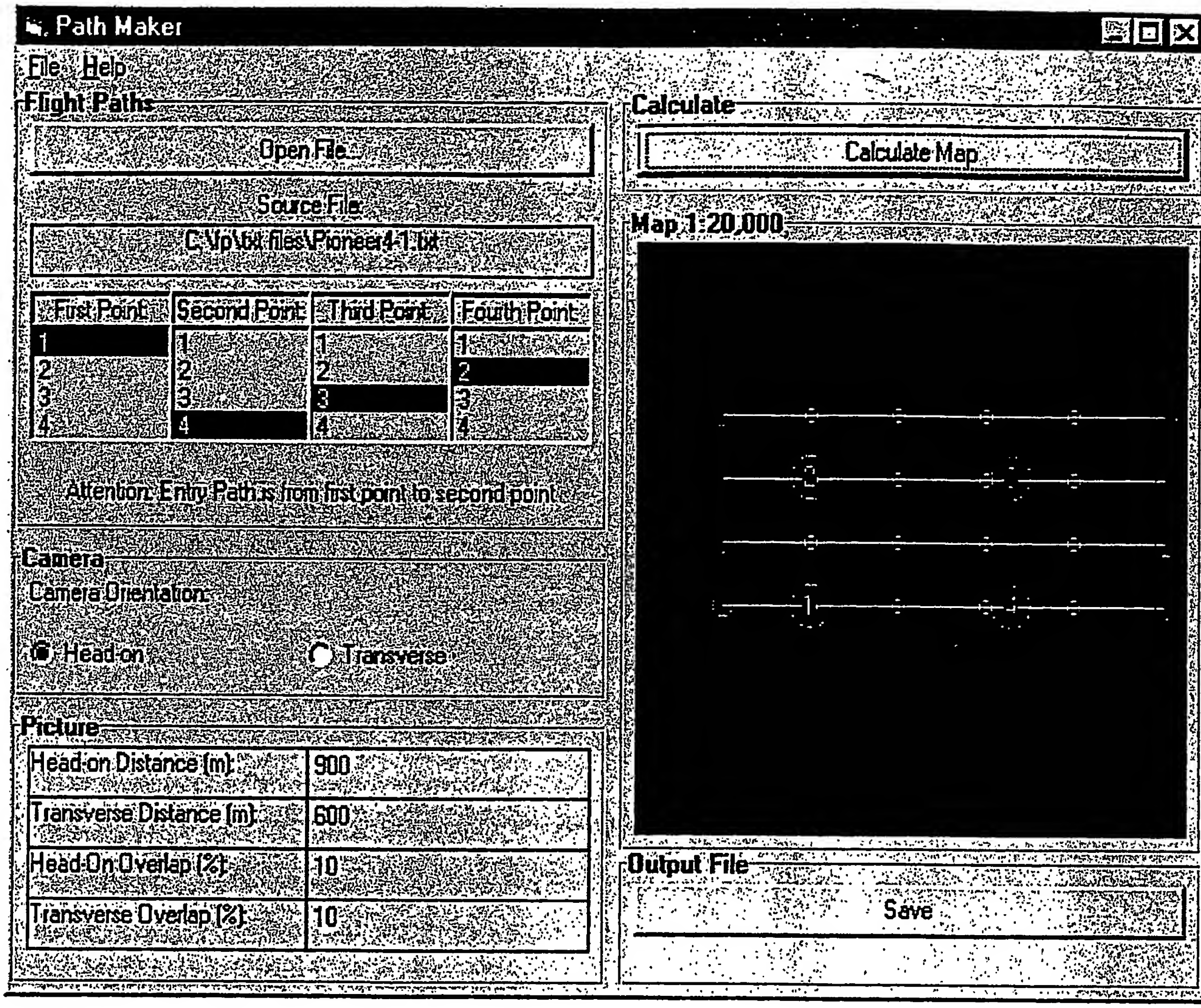
c. Mission Planning And Simulation

The mission planning is executed by a mapping program "turbo 4" and program "path maker". The operator marks on a map using the ground computer, area to be photographed. The borders of this marking are an input to the next program - "Path Maker". This Program defines photographing locations and flight paths, according to input parameters as resolution, overlap and etc. Output file of this program is a list of locations to be photographed by the airborne equipment. This file is tested and validated on the ground computer, by program "Flight Path" in simulation mode. This Program is the operating program on board. But in simulation mode on ground, using a virtual aircraft flying, one can test all the planned photographing locations, aircraft speed and direction.

Photography Area location by four corners marking



Flight paths and planned photography points



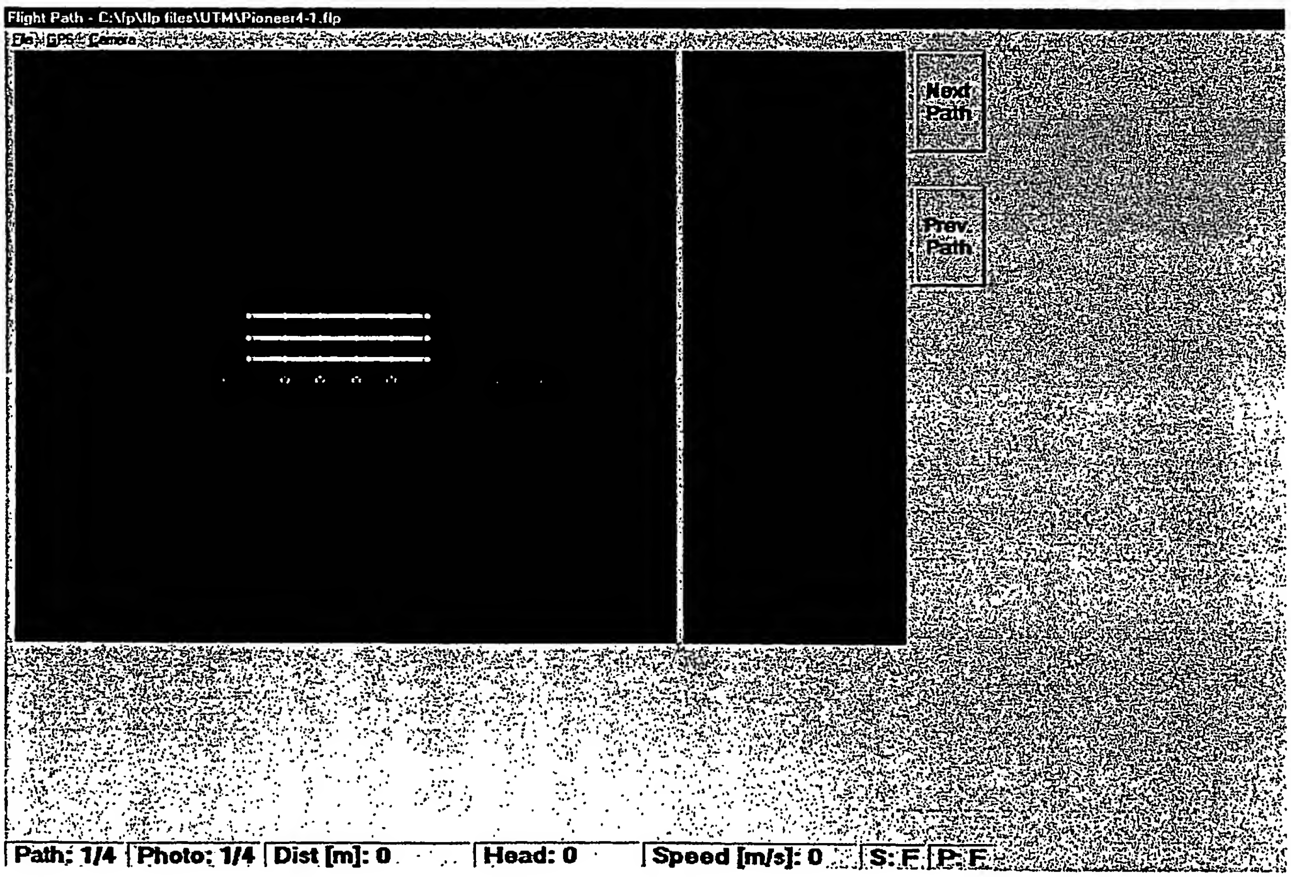
a. Flight execution

The output file from the "Path Maker", after simulation and validation is loaded to the airborne mission computer. The "flight Path" program reads this file and mark graphical direction how to fly over the required path on screens of the operator and pilot.

Once the aircraft location is closed to a planned photography point, the program software commands is given to the digital camera to take a picture. The digital image is stored in the mission computer disc combined with the navigation parameters - position and direction azimuth.

Based on PC-Anywhere software the flight path from the Mission Computer is duplicated on The Pilot Computer enabling the Pilot to follow the planned flying directions and give commands for execution.

Required Flight paths on screens of the operator and pilot



b. Image and Navigation Data Storage

For each photograph mission there is a file of navigation data. After each "Take Picture" command, a line of navigation data (location, speed, direction, time) is written to this file. Each picture has time tag in the image file.

On ground, image and data files from the Mission Computer are loaded to ground station computer database. The navigation data is merged to the image file so that post processing of data is done based on time location and flight data of each image.

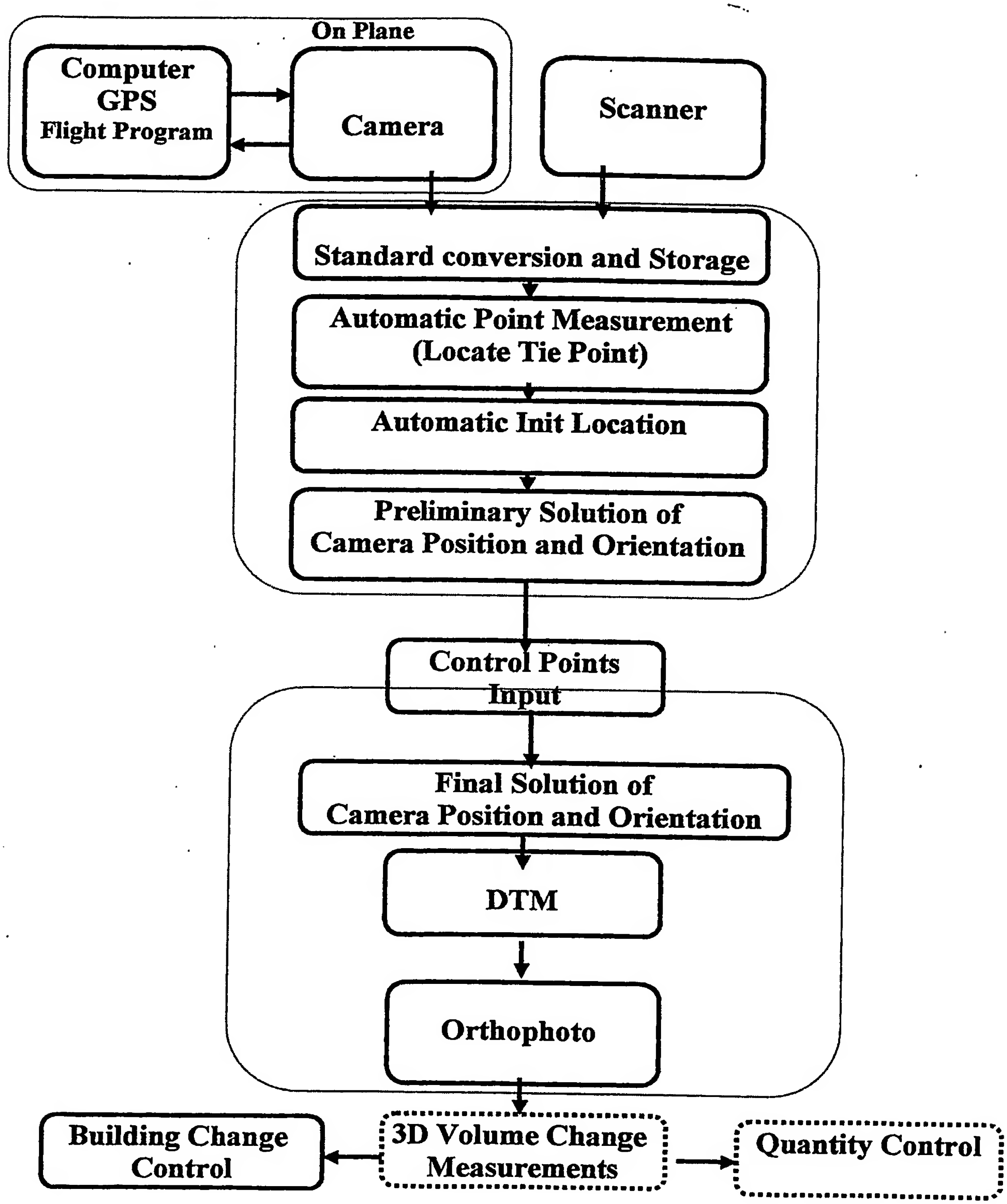
Subject No 3

Aerial Digital Data Processing Software System

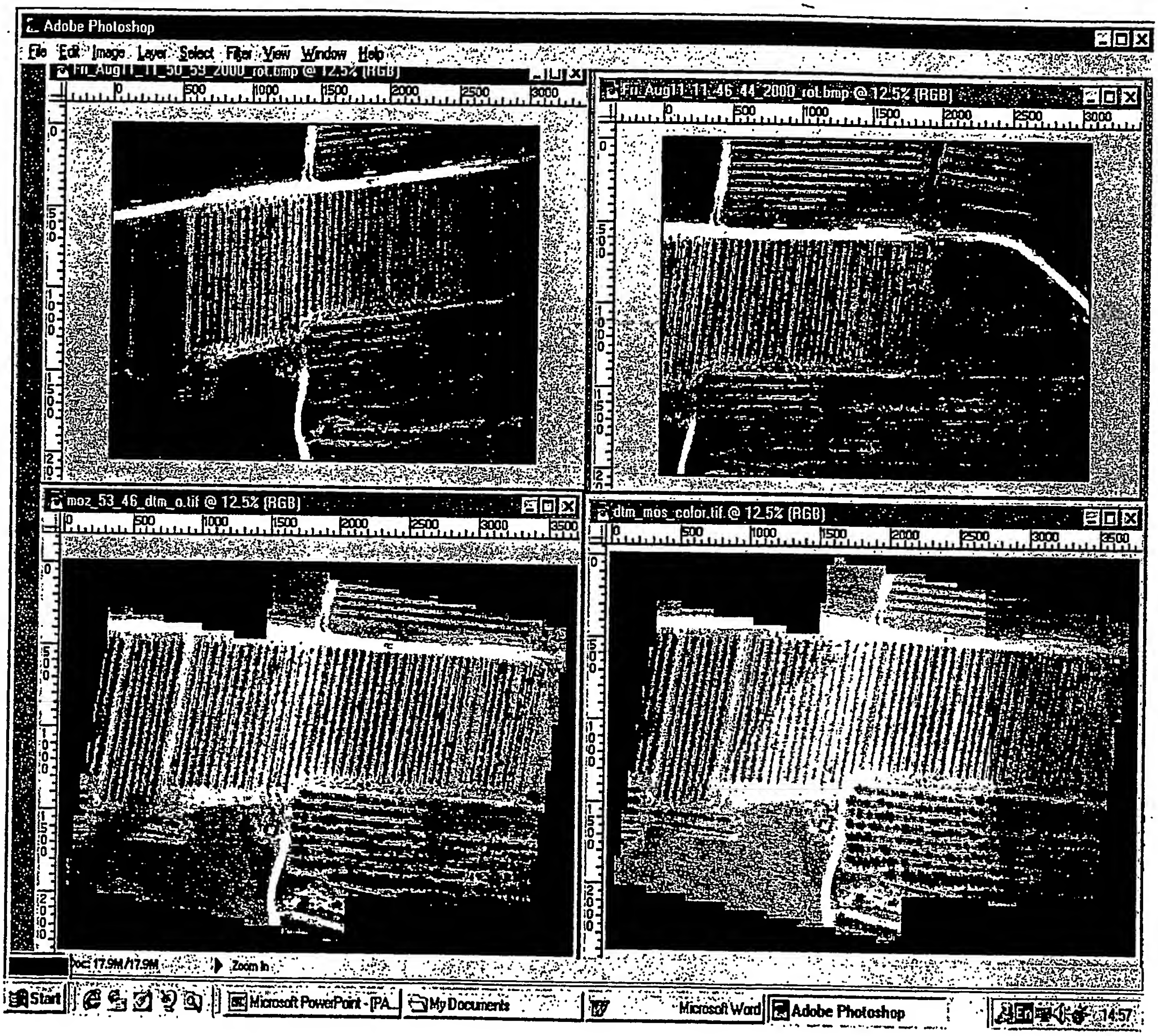
This software package includes the methods and algorithms for processing and analysis of digital (or digitized) aerial images. this software package enables the following operations:

- **Image import - transform** the input images into the Vitec standard.
- **Tie point measurements - locate** corresponding points in overlapping sets of images.
- **Triangulation solution** - computation of the camera locations and orientations for all the images.
- **Control points input** - interactive input of geodesic control points as measured on the ground.
- **Digital Terrain Model (DTM)** - computation of the DTM based on the stereoscopic information in overlapping images.
- **Mosaic generation** - combine the images into a rectified (Orthophoto) mosaic.
- **Change detection** - detect and measure changes between Orthophoto mosaics of the same target, taken in different times and different light conditions.
- **Change classification** - classify the detected change as belonging to a natural scene or to a man-made target.

Aerial Data Processing System flowchart



Automatic Orthophoto of country site



Aerial Data Processing Operators

1 Standard Conversion
The images to be processed are converted into the Vitec standard. The conversion includes *minification*, which creates an image pyramid for each input image. Each image pyramid consists of a sequence of replicas of the original image, where each image in the sequence is decimation with factor 2 of the previous one.

2 Automatic Init Location
3 D Correlator used for initial location based on overview low-resolution mosaic, in order to improve the location data of the GPS system. The data by this Correlator includes camera location e.g. x y z and flight azimuth.

3 Automatic Tie Point Measurement
This is a preliminary part of the Triangulation process, the process of finding the true parameters of the camera location and orientation, and the spatial orientation for each image. Pairs of tie points are located within the overlapped area of pairs of images. The location of the tie points is based on cross correlation computation within small image windows.

4 Preliminary Solution of Camera Position and Orientation
The parameters of the camera are estimated by solving a set of equations based on the detected tie points.

5 Interactive Input of Control Points
A set of four control points (minimum) is required in order to compute the earth coordinates of the image mosaic. The control points are points on the ground for which there are measured earth coordinates, including height. The points are marked in a way that enables to interactively locate them in the images.

6 Final Solution of the Camera Position and Orientation
The location and orientation of the camera for each image are computed based on the control points.

7 Digital Terrain Model (DTM) computation
The DTM is computed based on the stereoscopic information of the overlapped areas of pairs of images. It is required that there is an overlap of about 60% in order to obtain the DTM.

8 Orthophoto Mosaic

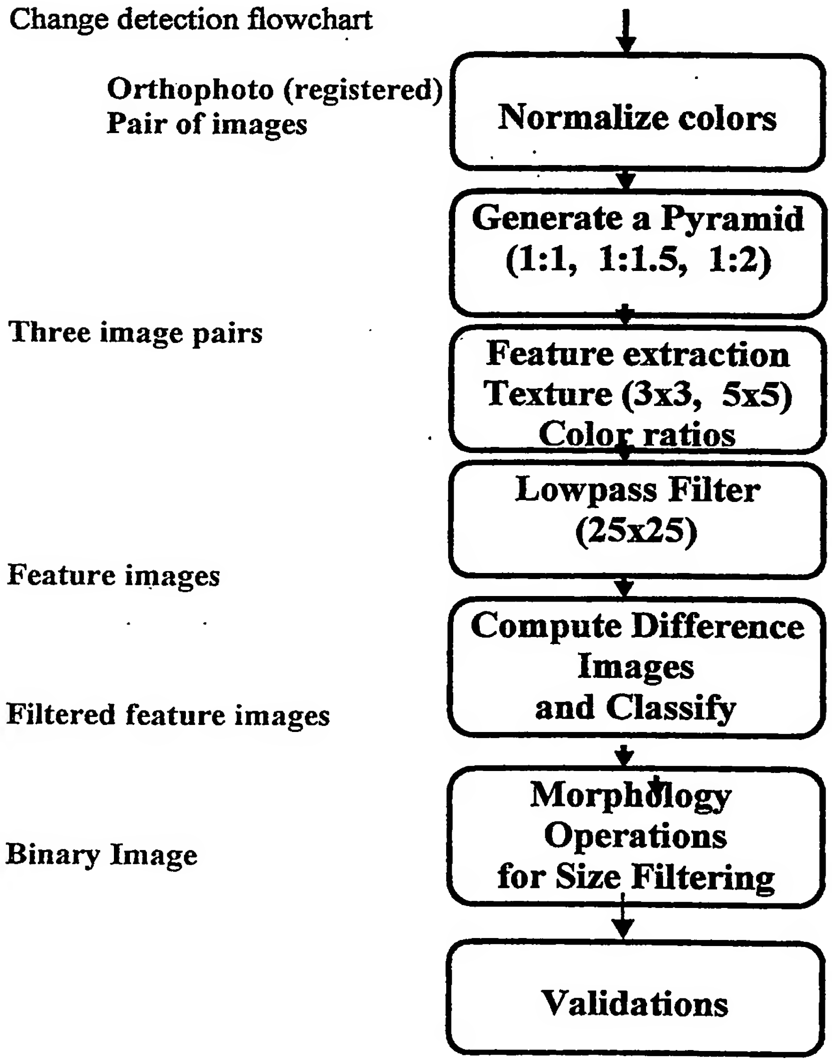
Once the camera location and orientation are known and a DTM is available, the Orthophoto mosaic can be calculated.

Subject No 4

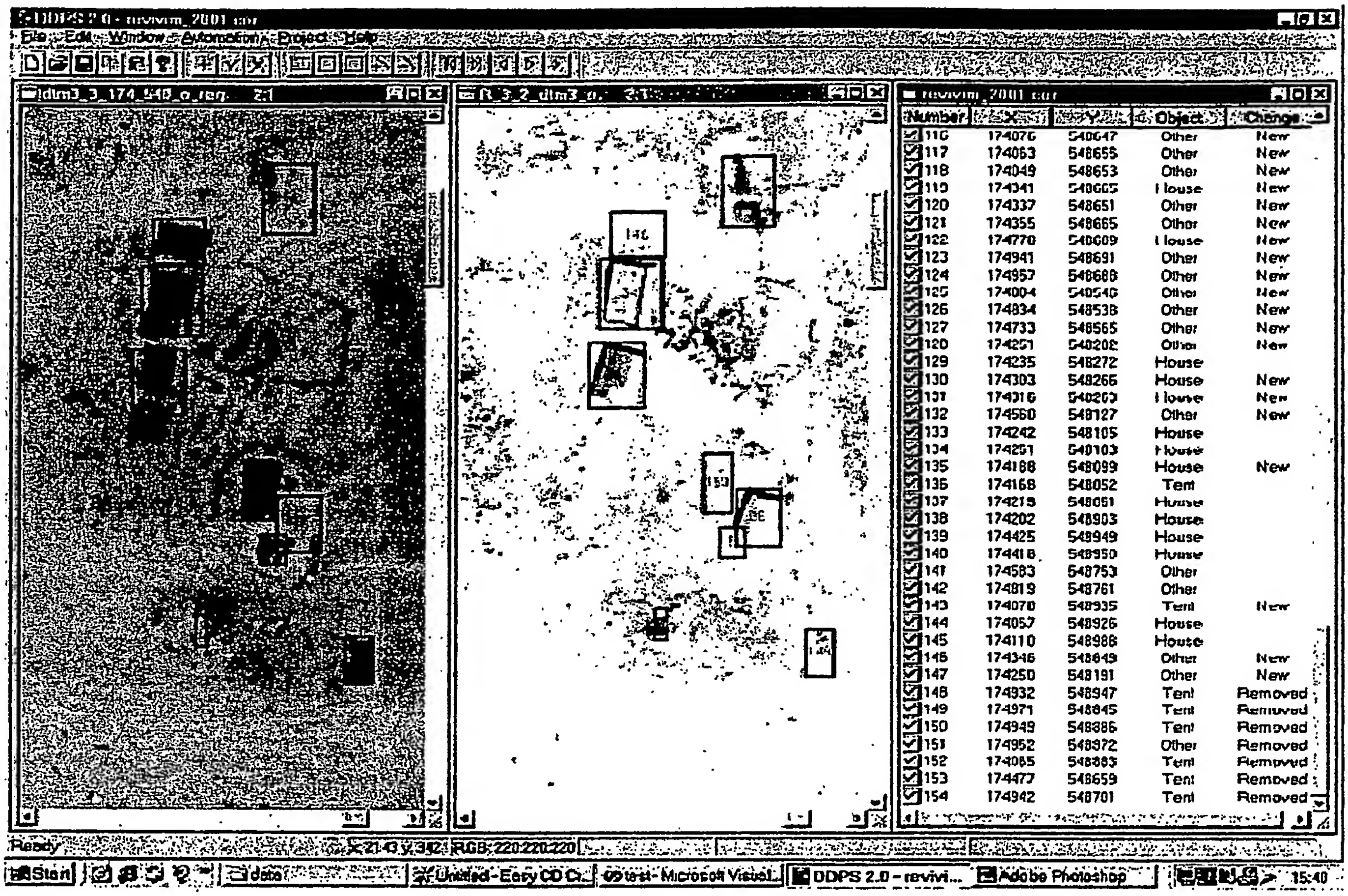
Change Detection

The aim of the change detection algorithm is to detect changes between pairs of images of the same target, taken at different times. The algorithm is designed to ignore changes due to illumination variations and differences in shadows. The input to this operation consists of Orthophoto of the initial period and images of the second period; the combined data is analyzed using the tie-points of the initial period as control points for the second period. Out of the combined data two mosaics with height data are derived; for the initial period and the second period.

Change detection flowchart



Change detection in Open Area

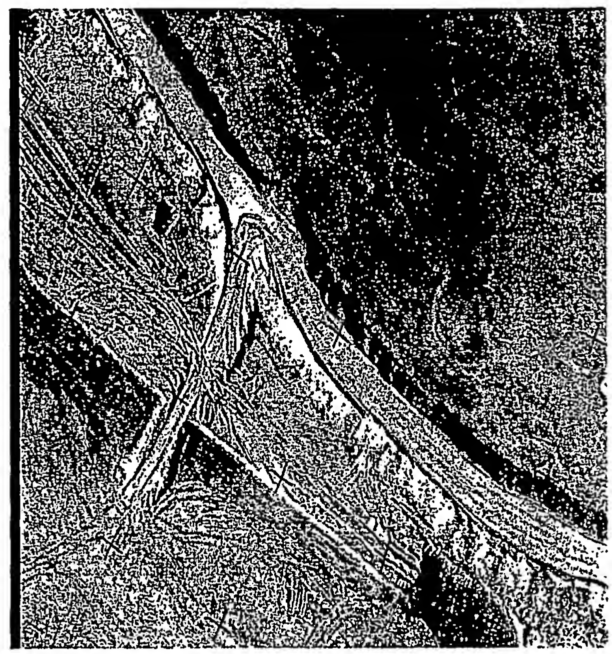


Open Mine Quantity Control

Change Detection and Volume Measurement

27 July 2001

20 July 2001



Change Detection Operators

1. Textural Features

The textural features used were proposed by Law (see attached pages), and are defined as follows:

Consider the following 3 vectors:

- ■チ $L_3=(1,2,1)$ Averaging
- ■リ $E_3=(-1,0,1)$ Edges
- ■ヌ $S_3=(-1,2,-1)$ Spots

The outer products of pairs of vector form 9 masks. Denote the masks by M_{3j}, $j=0,1, \ldots, 8$.

$$M_{30}=L^tL=\begin{matrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{matrix} \qquad M_{31}=E^tE=\begin{matrix} 1 & 0 & -1 \\ 0 & 0 & 0 \\ -1 & 0 & 1 \end{matrix} \qquad M_{32}=S^tS=\begin{matrix} 1 & -2 & 1 \\ -2 & 4 & -1 \\ 1 & -2 & 1 \end{matrix} \qquad \text{and so on.}$$

The mask M30 is used for normalization.

Let F and G be a pair of registered Orthophoto images.
Let FM_{3j} and GM_{3j}, $j=0, 1, \ldots, 8$ be the convolution of the respective image and the respective mask.
Let $B= FM_{30}/ GM_{30}$ be a brightness normalization coefficient.
Define a relative change measure in the following manner:

$$C_t= \sum_{j=1}^{8}(|FM_{3j}-GM_{3j}*B|)/\sum_{j=1}^{8}(|FM_{3j}|+|GM_{3j}*B|).$$

2. Colors Ratio Features

Parameter of Colors Ratio Feature calculates for every corresponding pixel according to formula:

$$C_c = K\sqrt{(R_r/S_r - R_t/S_t)^2 + (G_r/S_r - G_t/S_t)^2 + (B_r/S_r - B_t/S_t)^2},$$

where: K -scale coefficient for compatibility with textural features;
R_r, G_r, B_r -values of primary colors for reference image;

R_t, G_t, B_t -values of primary colors for test image;

$$S_r = \sqrt{R_r^2 + G_r^2 + B_r^2};$$
$$S_t = \sqrt{R_t^2 + G_t^2 + B_t^2}.$$

3. Features Selection

Features Selection is performed for every pixel according to a homogeneity measure within its vicinity. The homogeneity measure is calculated as follows:

$$H = \max(|FM_{31}|, |GM_{31} * B| \dots |FM_{38}|, |GM_{38} * B|).$$

Where all the parameters are as defined in the previous section.
If the value of H for the current pixel is more then a specified threshold, the textural features are used. If the value of H is less than the threshold, the colors ratio features are.
Calculation of the features is performed on the original image, and on replicas of the image obtained by decimation with factors of 1.5 and 2. The features computed for the three resolutions are respectively interpolated, and averaged.

4. Height Features

Local Digital Terrain Model (DTM) computation is performed for each changed aria using the height "Z " Volume computations and as Validator of the Change Detection validity.

5. Classification for change detection

The classification regarding the presence of the change is performed as follows. The feature matrix is smoothed by a Gaussian filter with a default sigma is 10. The filtered image is thresholded, and a relaxation process refines the thresholding. The result of this process is a binary image, where the value 1 in the image indicates presence of change between the images in the corresponding pixel, and the value 0 indicates that there is no change. After that we apply morphology operations on the binary image. The aim of these operations is to reduce the noise in the form of little separated objects or little holes in the big objects.

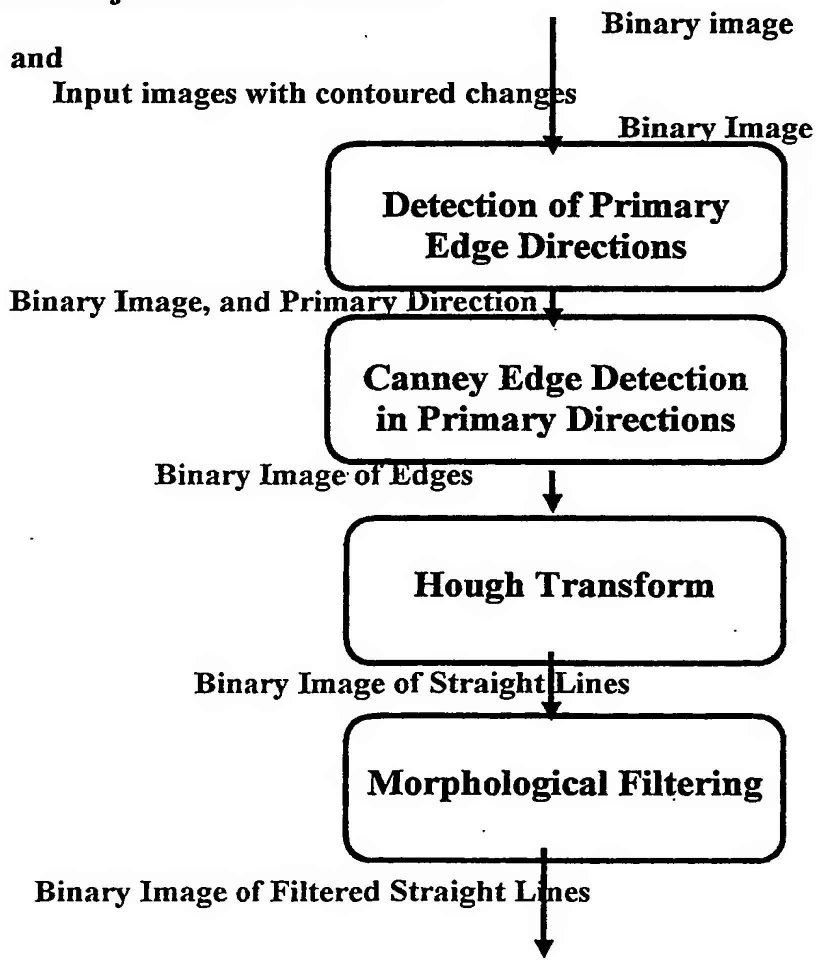
Subject No 5

Man-Made object detection

The aim of this operation is to detect man made objects within the regions that were classified as changes. It is assumed that man made objects have straight-line boundaries. and that within a relatively small neighborhood, the boundary lines are perpendicular. The man made object detection is performed as follows:

-Find the dominant edge direction.
-Perform edge detection in the dominant and the respective perpendicular direction.
-Detect of the straight-line segments.
-Classify the line segments as belonging or not belonging to man made objects.

Man-Made object detection flowchart



Automatic Construction Control

January 2001

July 2000

Man-Made object detection operators

1. Finding the dominant edge direction

For this process we use Canny edge detector (see attached paper). Information about direction of every edge element from this detector is used after quantization for computing the direction histogram of the edges. After low pass filtering of the histogram we consider the direction that corresponds to the histogram maximum, as the dominant edge direction.
From the direction histogram we find also the perpendicular edge direction as the local maximum of the histogram in the region shifted with regard to dominant edge direction by 90 degrees.

2. Edge detection in the dominant and the perpendicular direction

For edge detection in required directions we use have modified the Canny edge detector to suppress every edge direction except the required ones. As a result we get 2 binary images: image where edges are mainly in the dominant direction, and an image where edges are mainly in the perpendicular direction.

3. Detection of the straight-line segments

For detection of straight-line segments we use the Hough Transform (see attached material), which is applied to images with edges of dominant and perpendicular directions separately. We regard every edge pixel as belonging to straight line segments if the distance between a line after Hough Transform and this pixel is less then 1 pixel. As a result of this operation we get 2 binary images: with straight line segments in the mainly dominant and the mainly perpendicular directions correspondingly.

Subject No 6

Continues 3D Presentation of Aerial Images and Stereo Change Detection

This software module enables continues 3D presentation of serial aerial photographs without the need of operator's involvement by manual changing of photographs stereoscopic pairs.
The Stereo Change Detection is based on stereo mosaic, the stereo affect disappears were an object is missing or changed.
This capability is useful for detection, even on real-time, of moving objects (dynamic change detection mode) or changes occurred during the period between the two photography sessions (static change detection mode).
This software module includes the following blocks;

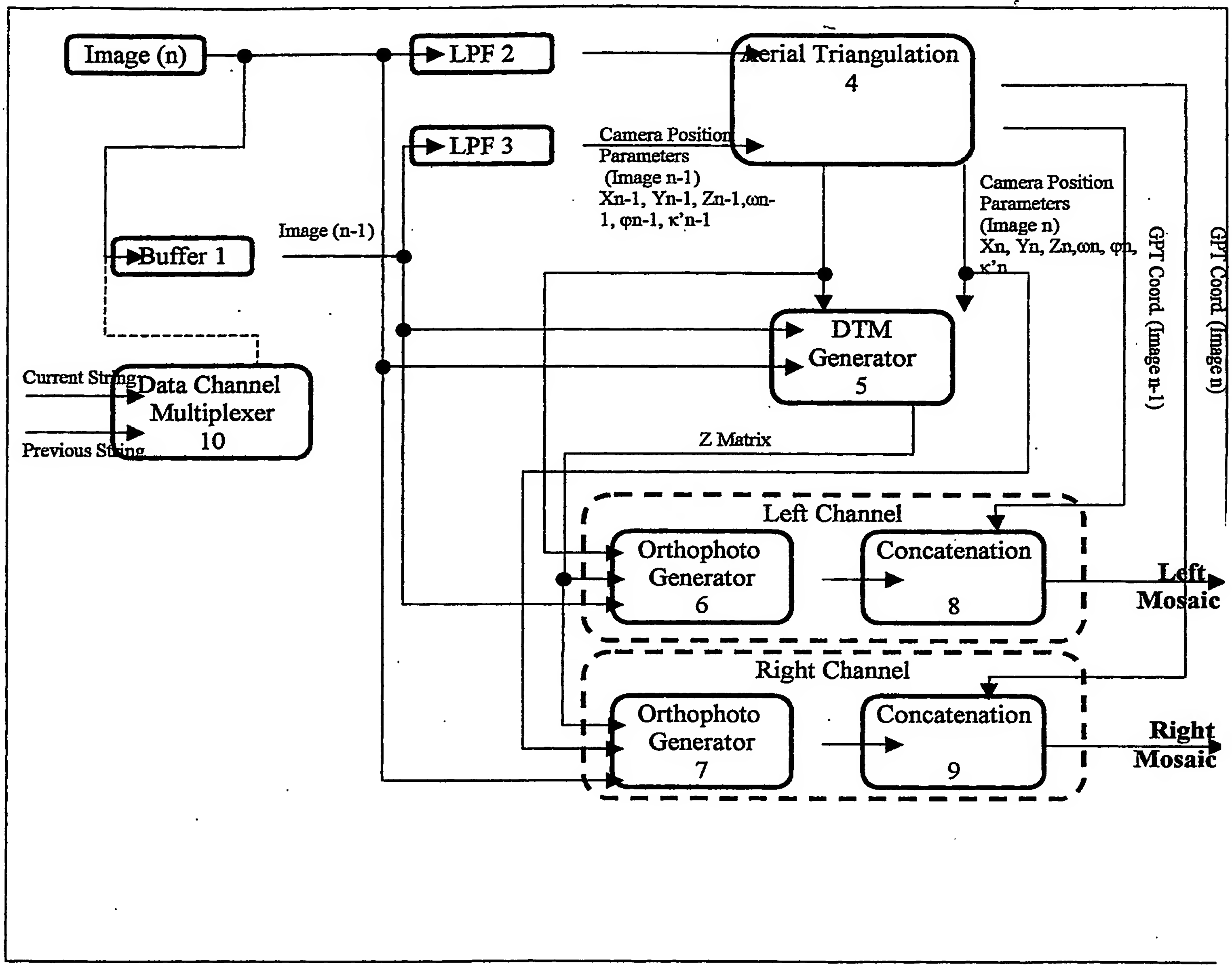
1. Buffer 1 for storing single photo.
2. Two identical blocks 2,3, for low pass filter.
3. Block 4, aero triangulation.
4. Block 5, DTM computation.
5. Two identical blocks 5,6, for Orthophoto generation.
6. Two identical blocks 8,9, for concatenation.
7. Block 10 in case of static change detection for data channel multiplexer.

Dynamic change detection mode.
The present frame together with the previous frame in buffer 1 are processed throw the low pass filter to aerial triangulation block, there is performed the camera location computations for each of the two frames including (x. y. z.) coordinates and (ω.φ.κ.) angles. At same time are done computations of the center of each photo coordinates. Using the low pass filter prior to aerial triangulation block improves the stability of the results.
On the next stage parameters of triangulation are transferred to the DTM block for surface heights, Z matrix computation for 10-20 points at each direction to the overlap area of the two photos.
Based on the DTM and camera location data, Orthophotos are created for each of the frames, as the height points are at low density, on the Orthophoto corrections are made only for wide areas, while on moderate areas and objects we are dealing with the correction is done, so the stereo effect is not disturbed. For example no change will be detected on a hill or road but will detect change of small object like man, vehicle or house.
On the last stage the two frames are added to the existing mosaics one to the right and the second to the left.

Static change detection mode.
The same as on the Dynamic change detection mode with one exception, before the data processing previous and present frames with the same GPS location data are transferred to block 10 – Data Channel Multiplexer, in specific order, each even photo comes from the present, each odd photo from the previous. Out of this block the process is the same as on the Dynamic change detection mode.

Continues 3D Presentation of Aerial Images and Stereo Change Detection

Flow chart



WHAT IS CLAIMED IS:

1. An automatic aerial digital photography and digital data processing systems essentially as described herein.

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